Real-Time Drifter and ADCP V(z) Observations of Kuroshio Intrusions on East China Sea Shelf

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LONG TERM GOALS

The long-term objective is to better understand the interactions between the Kuroshio and the East China Sea with the coordinated use of several tools, some of which already developed by ONR. We also plan to investigate the dynamical processes that govern this interaction.

To achieve this goal, new observations are being obtained with Surface Velocity Program (SVP) drifters array and a modified version of the ADOS-A used for the ONR sponsored NLIWI experiment.

The development of relatively inexpensive operational tools to provide real-time physical observations in a variety of marine environments is also one of our long term goals.

This research contributes to a more realistic prediction of this complex oceanic environment, which is located in area of strategic importance for PACFLEET operations.

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OBJECTIVES

The first objective is to measure the strength and the surface structure of the Kuroshio along the east coast of Taiwan and to the north-east of the island, and to observe the intrusion of the Kuroshio onto the southern East China Sea's continental shelf.

The second objective is to measure the circulation and physical processes on the southern East China Sea's continental shelf on a variety of spatial and temporal scales during the joint predictability experiment (Intensive Observing Period) in FY '09.

APPROACH

To accomplish the first objective, hundreds of SVP drifters were released in the Kuroshio and north-east of Taiwan to study the near-surface circulation.

To accomplish the second objective, a new instrument, called the R-ADOS-A (Restrained Autonomous Drifting Ocean Station with ADCP) was designed and tested in FY'08. The approach here was to use a spatially coherent array of several R-ADOS-A to measure the phase velocity of the internal tide, the local sub-tidal current profiles and the associated thermal structure.

WORK COMPLETED IN YF'08

Objective 1: Strength and surface structure of the Kuroshio

Two SVP drifters were released each week by the Taiwanese coast guard off Taidong (south-east Taiwan), starting on April 7, 2008. From January 14, 2009, one drifter per week was released. The deployments were concluded on September 16, 2009. A total of 112 drifters were released. The data were made available to the QPE investigators at: http://www-pord.ucsd.edu/~yykim/drifters/QPE2008/QPE.html . The drifter's tracks were routinely overlaid to maps of satellite altimetry observations computed from the AVISO SLA data. Those data will be thoroughly analyzed in FY'10, the third year of this proposal.

During the IOP 88 more SVP drifters were released: the first deployments of 44 units occurred from the Taiwanese R/V OR2 and OR3 in August 2009, in support of the data collection operations to set-up the numerical models boundary conditions; the second deployments occurred from the R/V Roger Revelle in the IOP box where 44 SVP-GPS drifters were deployed in August-September 2009. Figures

1 to 4 summarize the drifter deployments.

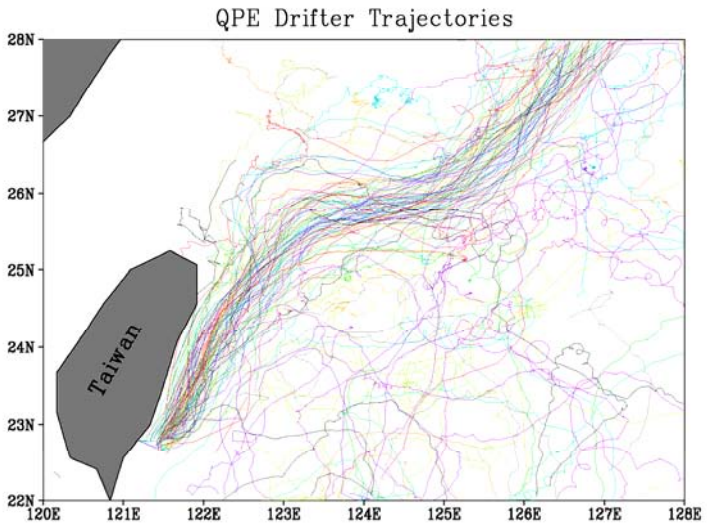

Figure 1: Spaghetti diagram of the 112 SVP drifters released in the Kuroshio by the Taiwanese coast guard from April 7, 2008 to September 16, 2009.Other buoys drifting in the area and deployed by other programs are also shown.

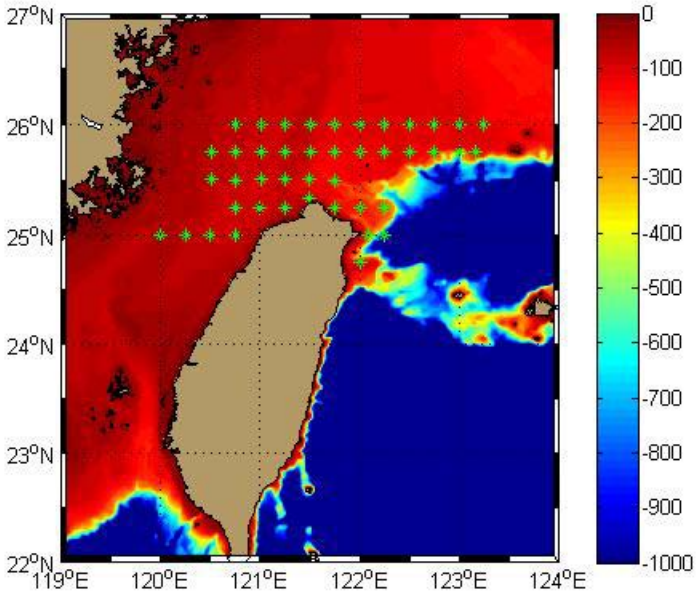

Figure 2: Deployment locations of the 44 SVP drifters deployed from R/V's OR2 and OR3.

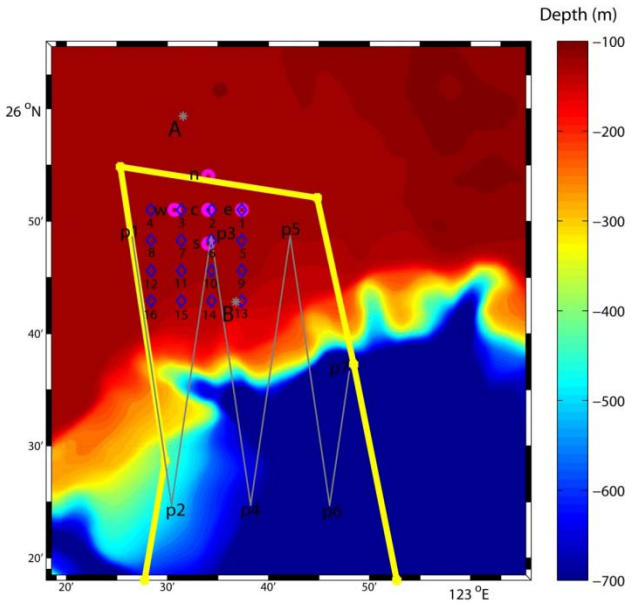

Figure 3: Deployment locations. Blue diamond: SVP drifters. Pink circles: R-ADOS-A. Grey Lines: ADCD/HDS/thermosalinograph transects.

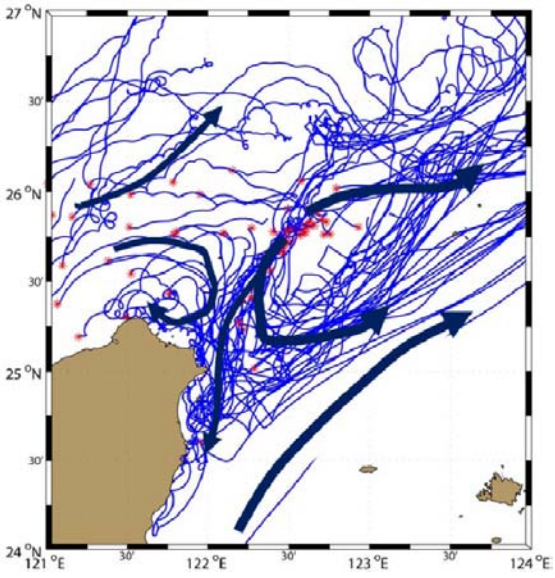

Figure 4: Tracks of the 88 drifters deployed during the IOP. The arrow depicts the near-surface ocean currents.

Objective 2: Internal tide observations and local circulation within the IOP box

We completed the design of the R-ADOS-A and the test deployments in FY'08 (See Figure 5 for a schematic of the R-ADOS-A).

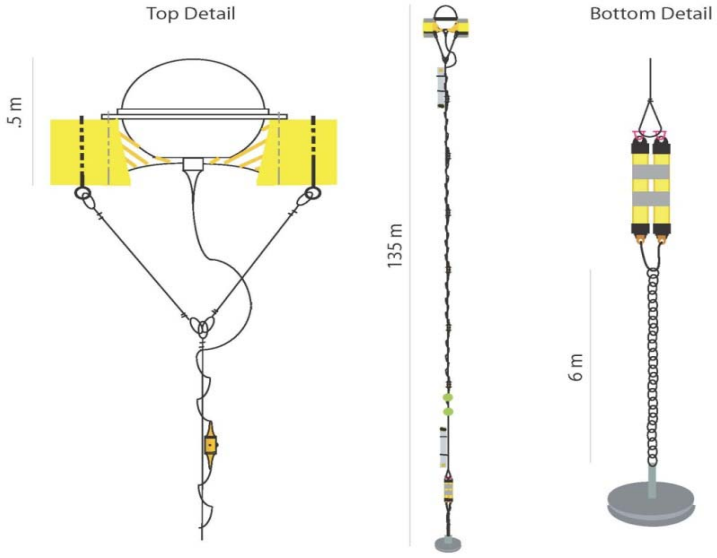

Figure 5: Schematic of the R-ADOS-A. The top detail shows the spherical ABS buoy that contains the batteries and the electronics. The ABS buoy in mounted onto the yellow "doughnut" shaped foam ring for extra buoyancy. Underneath is a schematic of the cables assembly and of a thermistor/pressure pod. The mid picture shows two ADCP's clamped on the cable. However, only on ADCP was used for the QPE pilot cruise. The bottom details show the assembly of the shallow water acoustic releases.

In FY '09 we spent more efforts to improve the design of the deployment spool, i.e. by eliminating paper tape and using Velcro straps instead, resulting in a tidier and smaller package and easier to service set-up (Figure 6).

This set up was extensively tested off Point Loma (San Diego, CA) before the final production of the five units begun.

An inductive modem for integrating the ADCP measurements with the stream of data from the GPS, the temperature and the pressure sensors was also designed and built.

A complete real-time data transmission was implemented using the RUDICS system (Iridium). The full resolution data was sent at 90 seconds intervals.

Five units were assembled and successfully deployed in the East China Sea from August 13, 2009 through September 15, 2009. All five units were successfully recovered.

All of the measurements from the R-ADOS-A instruments and from the surface drifters were made available in real time to the QPE investigators (http://qperealtime.ucsd.edu/).

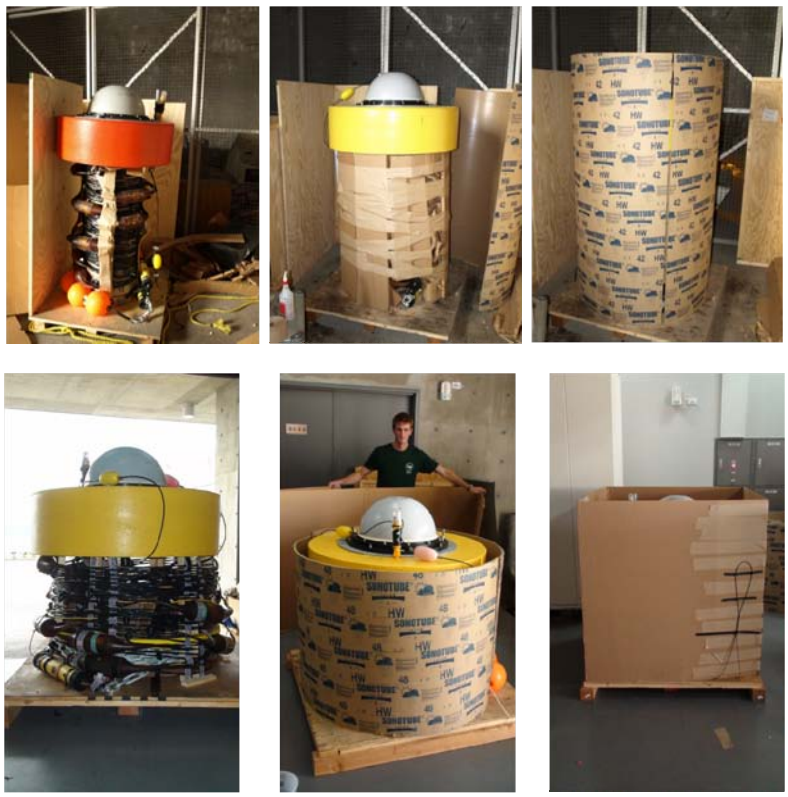

Figure 5: Top: the 2008 R-ADOS-A set-up. Bottom: the 2009 R-ADOS-A set-up.

To protect the R-ADOS-A array we chartered a fishing boat and crew, which guarded the array for the entire duration of the experiment. The pictures below documents a snatching attempt from two Chinese fishing boats, which was unsuccessful due to the prompt intervention of the R/V Roger Revelle and the chartered Taiwanese fishing boat (Figure 6).

Other standard oceanographic observations were carried out from the R/V R. Revelle during our cruise, August 13-21, 2009. See appendix for a short cruise report.

Figure 6: a Chinese fishing boat trying to bring one R-ADOS-A onboard.

RESULTS

Since a systematic data analysis is just starting, here we present only few preliminary results.

The analysis of the newly released Kuroshio drifters and of the historical dataset revealed that intrusions of the Kuroshio on the ECS continental shelf should occur at least at two different locations, i.e. north-east of Taiwan and south of 25 N, and north of 25 N (Figure 7).

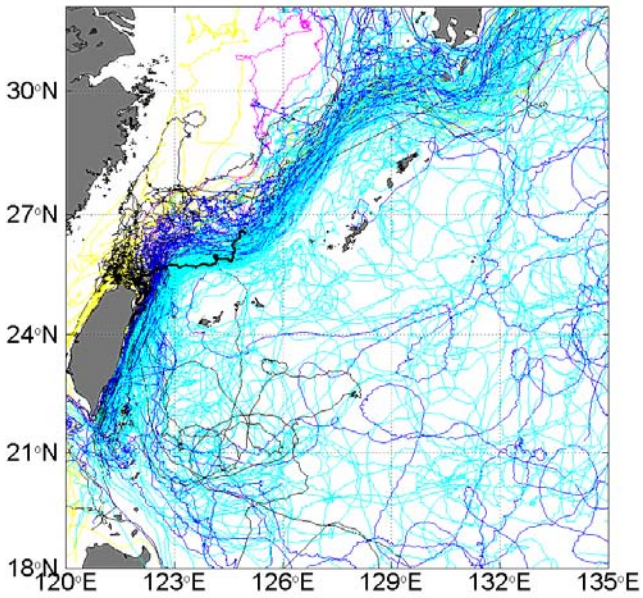

Figure 7: SVP drifter tracks. The black tracks denote the southern intrusion and the blue tracks denote the northern intrusion.

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During our QPE IOP cruise, from August 13, 2009 to August 21, 2009 (R/V R. Revelle) a salinity map compiled from the ship's thermo-salinograph data is suggesting the existence of a shingle (i.e. an eddy spun-off from the Kuroshio) or of a meander-like intrusion of Kuroshio occurring in the QPE-IOP area (Figure 8).

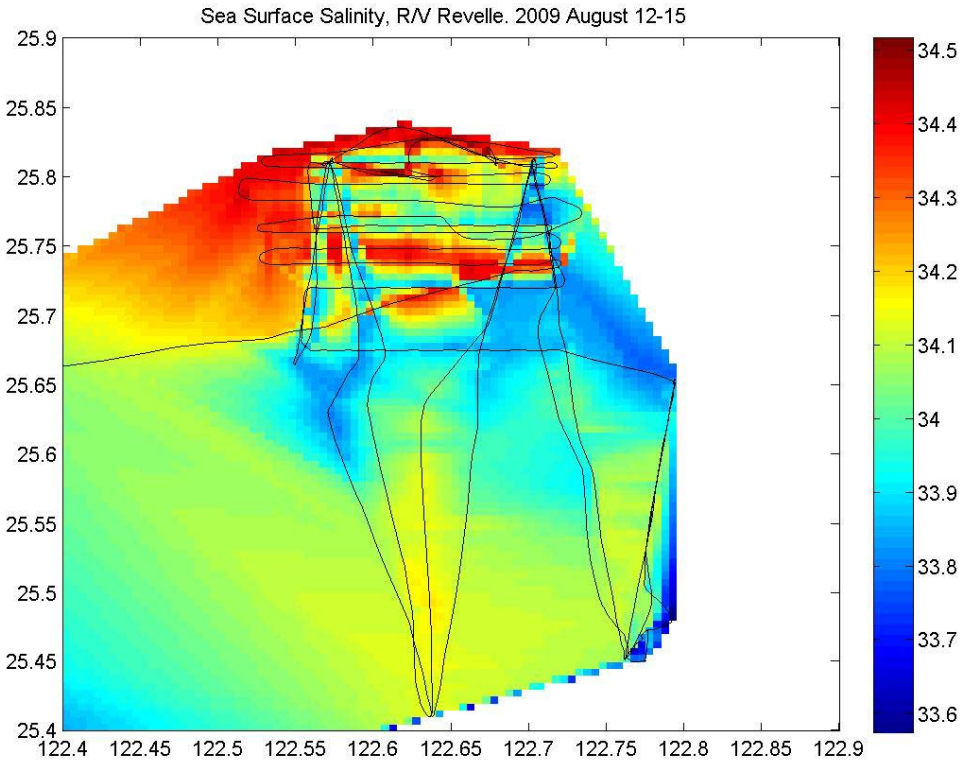

Figure 8: Sea surface salinity. Note the the high salinity water of Kuroshio origin intruding onto the ECS continental shelf. The black line is the ship's track. The data were collected during August 12-15, 2009.

The existence of a shingle could be consistent with the near-surface circulation pattern revealed by the drifters in figure 4, where a south-westward current exist just north-east of Taiwan, between the coast and the Kuroshio.

Task2: Results from the R-ADOS-A deployment

Numerous lessons were learned from the R-ADOS-A deployments. While the design of the deployment spool has now reached full maturity with 6 successful deployments out of 6, some work

could still be done to improve the ability of the instrument to withstand strong currents without drifting relatively long distances. The R-ADOS-A is designed to remain afloat if it drifts in water deeper than its overall length, so adding more weight to the bottom of the chain is not a viable option, but the shape of the surface buoy could be changed to reduce the surface drag.

During the QPE -IOP the motion of the R-ADOS-A was constantly monitored due to the close proximity of the shelf break (~ 8 nautical miles) and of the swift Kuroshio flowing nearby. While mesoscale currents were generally weak (< 0.5 m/s) strong tidal flows (in excess of 1.2 m/s across the water column) would shift the R-ADOS-A with speed of the order of 0.6 m/s (Figure 9). Such challenging conditions required the array to be towed inshore during the spring-tide peak. No other interventions were required during the month-long deployment.

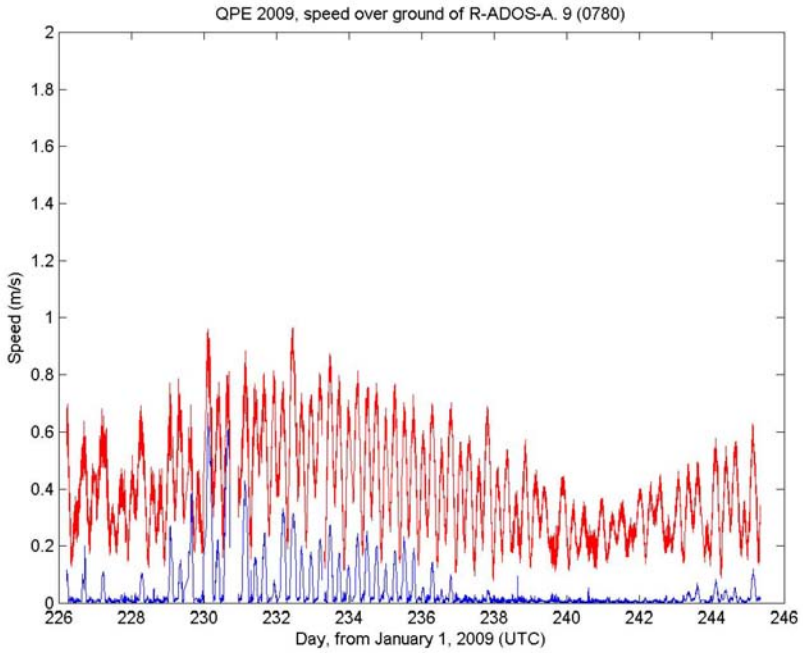

Figure 9: depth averaged (20-100 m) ocean horizontal speed (red) and speed of the R-ADOS-A (blue).

The real-time data transmission efficiency is being evaluated now, but we don't expect to find major problems as it already appears that most of the data was recovered through the satellite link.

Two spring tide events were sampled by the R-ADOS-A array, associated with strong internal tides and non-linear internal waves packets (Figure 10 through 12), also observed with ship-board sensors (Figure 13).

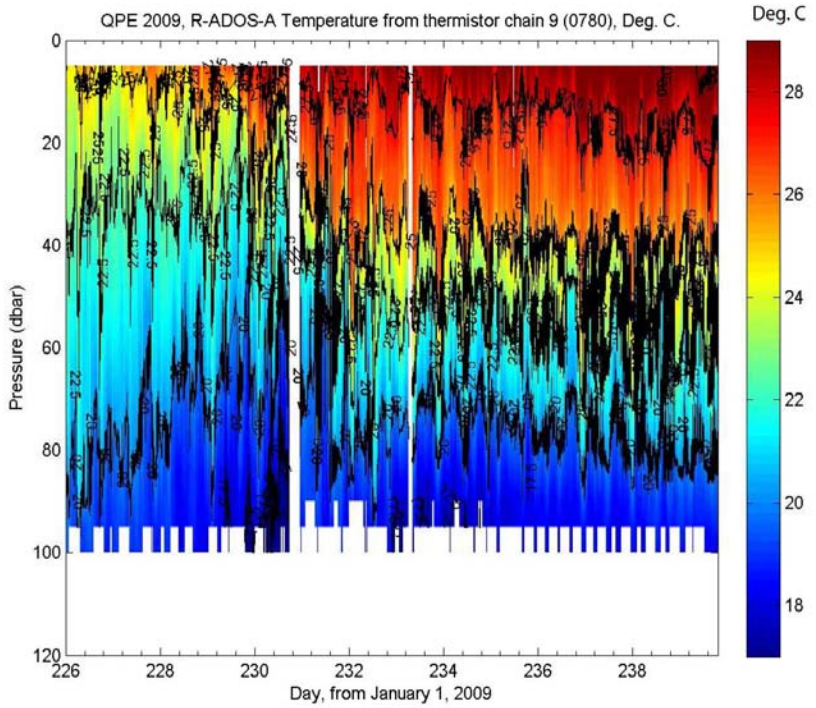

Figure 10: Vertical temperature profile time series from one R-ADOS-A during around the first spring tide event (~ day 232).

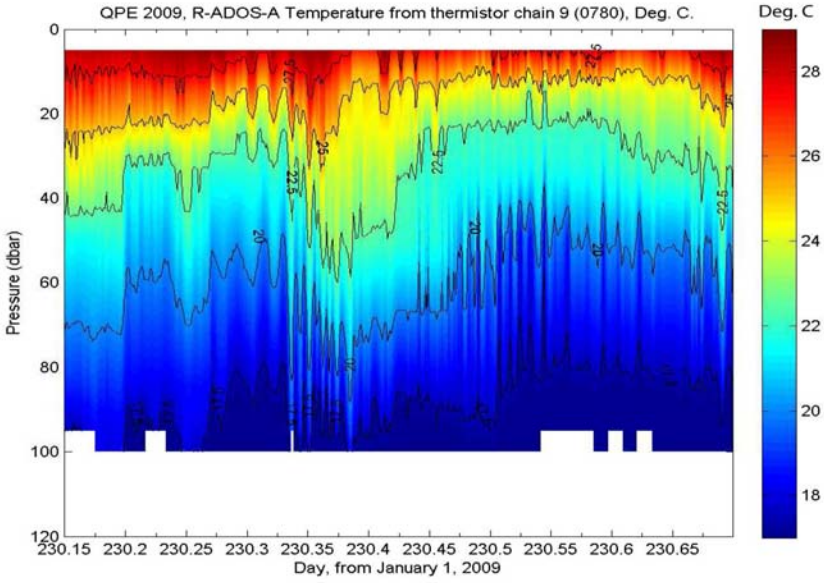

Figure 11: As figure 10. Expanded view showing several internal waves packets superimposed to the internal tide

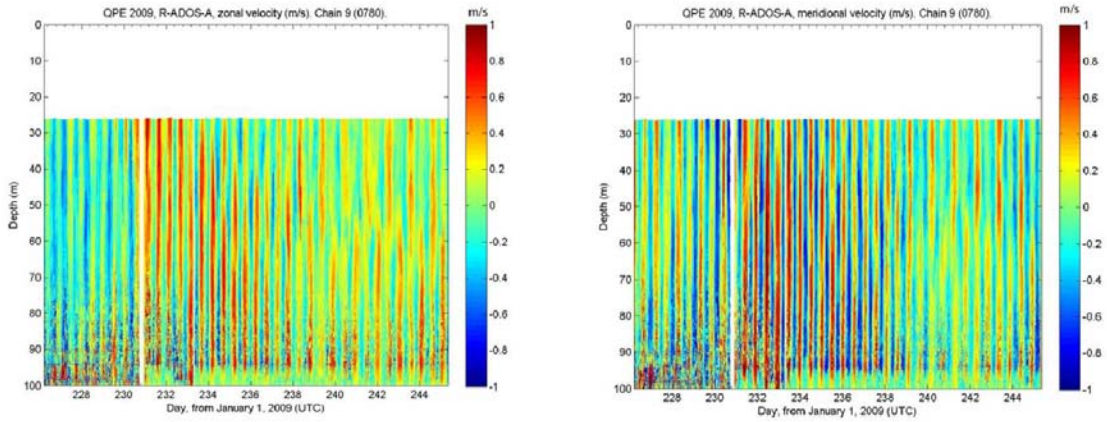

Figure 12: ADCP velocity profiles from ine R-ADOS-A (left: zonal velocity, right: meridional velocity) around the first spring tide event.

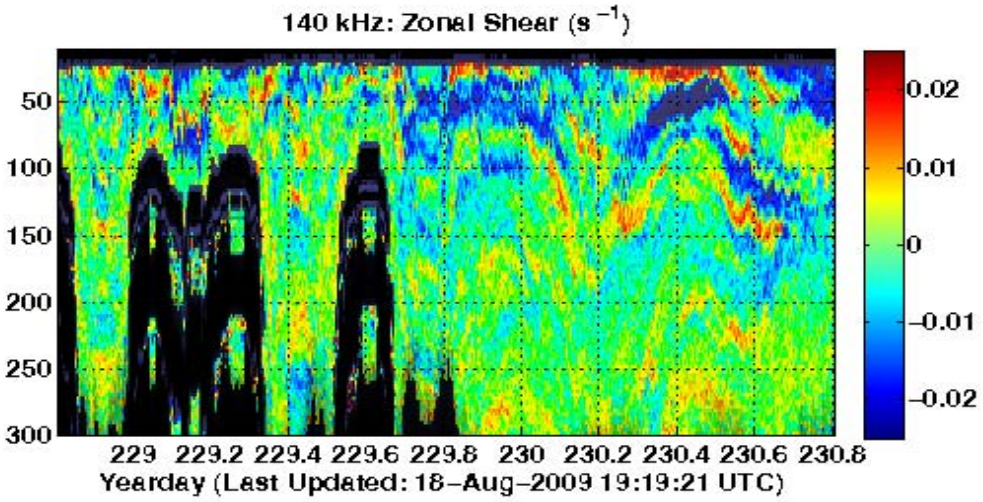

Figure 13: Zonal shear at 25 36.00N. 122 41.65E observed during a stationary 30 hours long time series, starting at approximately day 230.

As during the pilot experiment, the ECS continental shelf proved again to be a very difficult area to work in due to very high fishing pressure, and chartering the fishing boat proved to be a very good investment.

IMPACT/APPLICATIONS

The R-ADOS-A design has been upgraded from the FY ’08 version. Newly built instruments delivering data in real time and are now available.

The SVP drifter data (ARGOS positions) were placed on the GTS for use by global scientific community.

TRANSITIONS

N/A

RELATED PROJECTS

NOAA/OGP funded the “Global Drifter Program”.

APPENDIX: MEASUREMENTS PERFORMED DURING R/V R. REVELLE CRUISE, AUGUST 13-21, 2009.

U.S. Dept. of State CRUISE No.:	2009-017
SHIP NAME:	Roger Revelle
OPERATING INSTITUTE OR AGENCY:	Scripps Institution of Oceanography
PROJECT TITLE:	Quantifying, Predicting, and Exploiting Uncertainty Experiment (QPE)
CRUISE DATES (INCLUSIVE):	08/13/2009-08/21/2009

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CLEARANCE COUNTRIES:	Taiwan and Japan
FOREIGN PARTICIPANTS:	Luca Centurioni; Chang, Ching-ming; Chen, I-hsiang; Chen, Wen-yu; Cheng, Chun-hsiang; Chiang, Hsin-lun; Hsu, Chia-wei; Hwu, Grace; Lan, Cheng-yu; Li, Chun-huei; Li, Sung-lan; Tseng, Chiung-jung; Wang, Tsai-yu; Wang, Ya-jen; Yang, Yi-chou; Yeh, Chin-chou;

DESCRIPTION OF SCIENTIFIC PROGRAM (include page-sized chartlet showing cruise track):

The oceanic processes controlling mesoscale/sub-mesoscale horizontal and vertical temperature gradients, including features such as surface and bottom mixed layer structure, fronts and intrusions, act over a broad range of temporal and spatial scales. For the shelf-slope system in the Southern ECS, dominant processes include Kuroshio intrusion, cold dome, internal tides, NLIWs, and inertial waves. These oceanic processes govern East China Sea shelf/slope T-S variability at time scales ranging from minutes to days, thus exerting strong impacts on acoustic performance and representing significant environmental sources of uncertainty in predictions of acoustic performance.

An integrated physical and acoustical oceanography experiment is designed to quantify effects of physical processes on the acoustic propagation and sonar performance. This cruise is to perform one component of the integrated field observational program.

During this cruise (track in figure 1), we performed the following activities:

1) deployed five restrained ADOS-A and a CTD cast was taken at each deployment location (blue asterisks in Figure 2) to study the shelf circulation and the internal tide;
   25 48.56N. 122 37.36E. RADOSA #1 deployed 2350z 08/13/09
   25 47.98N. 122 38.39E. RADOSA #2 deployed 0100z 08/14/09
   25 48.51N. 122 33.96E. RADOSA #3 deployed 0206z 08/14/09
   25 50.08N. 122 37.23E. RADOSA #4 deployed 0308z 08/14/09
   25 48.55N. 122 40.70E. RADOSA #5 deployed 0523z 08/14/09

2) deployed thirty-two SVP drifters (magenta asterisks in Figure 2) to study the shelf circulation;

25 48.55N. 122 42.61E. SVP #1 deployed 0620z 08/14/09
25 48.56N. 122 39.72E. SVP #2 deployed 0640z 08/14/09
25 48.55N. 122 36.67E. SVP #3 deployed 0702z 08/14/09
25 48.58N. 122 33.68E. SVP #4 deployed 0723z 08/14/09
25 45.92N. 122 33.70E. SVD #5 deployed 0746z 08/14/09
25 45.86N. 122 36.72E. SVD #6 deployed 0809z 08/14/09
25 45.88N. 122 39.65E. SVP #7 deployed 0829z 08/14/09
25 45.87N. 122 42.71E. SVP #8 deployed 0847z 08/14/09
25 43.37N. 122 43.35E. SVP #9 deployed 0907z 08/14/09
25 43.17N. 122 39.79E. SVP #10 deployed 0930z 08/14/09
25 43.17N. 122 36.71E. SVP #11 deployed 0948z 08/14/09
25 43.17N. 122 33.56E. SVP #12 deployed 1006z 08/14/09
25 40.44N. 122 33.71E. SVP #13 deployed 1025z 08/14/09
25 40.46N. 122 36.67E. SVP #14 deployed 1044z 08/14/09
25 40.46N. 122 39.80E. SVP #15 deployed 1103z 08/14/09
25 40.47N. 122 42.71E. SVP #16 deployed 1119z 08/14/09
25 32.87N. 122 43.50E. SVP #17 deployed 1837z 08/19/09
25 38.20N. 122 43.50E. SVP #18 deployed 1907z 08/19/09
25 43.62N. 122 43.50E. SVP #19 deployed 1935z 08/19/09
25 48.79N. 122 43.49E. SVP #20 deployed 2001z 08/19/09
25 33.40N. 122 39.50E. SVP #21 deployed 0653z 08/19/09
25 43.32N. 122 40.20E. SVP #22 deployed 0425z 08/20/09
25 38.23N. 122 40.19E. SVP #23 deployed 0451z 08/20/09
25 32.94N. 122 40.20E. SVP #24 deployed 0518z 08/20/09
25 33.03N. 122 36.90E. SVP #25 deployed 1046z 08/20/09
25 38.20N. 122 36.91E. SVP #26 deployed 1117z 08/20/09
25 43.57N. 122 36.91E. SVP #27 deployed 1155z 08/20/09
25 48.70N. 122 36.89E. SVP #29 deployed 1229z 08/20/09
25 48.48N. 122 33.45E. SVP #30 deployed 1254z 08/20/09
25 43.37N. 122 33.59E. SVP #30 deployed 1328z 08/20/09
25 37.86N. 122 33.60E. SVP #31 deployed 1404z 08/20/09
25 33.01N. 122 33.61E. SVP #32 deployed 1436z 08/20/09

3) Six transects (green lines in Figure 2) involving CTD casts (green asterisks in Figure 2), bongo nets (red open circles in Figure 2) and the Hydrographic Sonars to map the edge of the Kuroshio;

25 39.21N. 122 47.60E. CTD #6 deployed 1204z 08/14/09
25 27.08N. 122 45.72E. CTD #7 deployed 1404z 08/14/09
25 48.66N. 122 42.13E. CTD #8 deployed 1645z 08/14/09
25 24.70N. 122 38.23E. CTD #9 deployed 1935z 08/14/09
25 48.64N. 122 34.31E. CTD #10 deployed 2242z 08/14/09
25 39.85N. 122 32.97E. CTD #11 deployed 0002z 08/15/09
25 48.71N. 122 34.34E. CTD #12 deployed 0212z 08/15/09
25 24.70N. 122 38.24E. CTD #13 deployed 0525z 08/15/09
25 48.67N. 122 42.15E. CTD #14 deployed 0830z 08/15/09
25 27.14N. 122 45.73E. CTD #15 deployed 1124z 08/15/09
25 39.21N. 122 47.61E. CTD #16 deployed 1340z 08/15/09
25 27.04N. 122 45.94E. CTD #17 deployed 1525z 08/15/09
25 48.68N. 122 42.11E. CTD #18 deployed 1812z 08/15/09
25 24.78N. 122 38.31E. CTD #19 deployed 2114z 08/15/09
25 48.70N. 122 34.35E. CTD #20 deployed 0016z 08/16/09
25 39.85N. 122 32.93E. CTD #21 deployed 0142z 08/16/09
25 48.69N. 122 34.36E. CTD #22 deployed 0304z 08/16/09
25 24.70N. 122 38.23E. CTD #23 deployed 0610z 08/16/09
25 48.84N. 122 42.20E. CTD #24 deployed 0902z 08/16/09
25 27.32N. 122 45.92E. CTD #25 deployed 1147z 08/16/09
25 39.21N. 122 47.54E. CTD #26 deployed 1330z 08/16/09
25 22.08N. 122 45.87E. CTD #27 deployed 1605z 08/16/09
25 48.64N. 122 42.15E. CTD #28 deployed 1910z 08/16/09
25 24.75N. 122 38.26E. CTD #29 deployed 2200z 08/16/09
25 48.64N. 122 34.32E. CTD #30 deployed 0106z 08/17/09
25 39.29N. 122 33.41E. CTD #31 deployed 0246z 08/17/09
25 48.68N. 122 34.30 E. CTD #32 deployed 0620z 08/17/09
25 24.48N. 122 38.41E. CTD #33 deployed 0954z 08/17/09
25 48.64N. 122 42.14E. CTD #34 deployed 1430z 08/17/09
25 27.24N. 122 45.88E. CTD #35 deployed 1755z 08/17/09
25 39.14N. 122 47.56E. CTD #36 deployed 2015z 08/17/09

25 24.27N. 122 38.57E. Bongo #3 deployed 1020z 08/17/09

25 48.65N. 122 42.12E. Bongo #4 deployed 1444z 08/17/09

25 27.29N. 122 46.53E. Bongo #5 deployed 1822z 08/17/09

25 39.13N. 122 47.57E. Bongo #6 deployed 2036z 08/17/09

4) A 30 hour long CTD time series and bongo net sampling at 25 36.00N. 122 41.64E (cyan open circle, Figure 2). The following hourly CTD casts were taken:

25 36.00N. 122 41.65E. CTD #37 deployed 2204z 08/17/09

25 36.01N. 122 41.66E. CTD #38 deployed 2331z 08/17/09

25 35.96N. 122 41.73E. CTD #39 deployed 0005z 08/18/09

25 36.09N. 122 41.63E. CTD #40 deployed 0122z 08/18/09

25 35.99N. 122 41.67E. CTD #41 deployed 0220z 08/18/09

25 35.98N. 122 41.63E. CTD #42 deployed 0306z 08/18/09

25 35.99N. 122 41.59E. CTD #43 deployed 0415z 08/18/09

25 35.99N. 122 41.62E. CTD #44 deployed 0536z 08/18/09

25 36.01N. 122 41.64E. CTD #45 deployed 0603z 08/18/09

25 35.98N. 122 41.63E. CTD #46 deployed 0705z 08/18/09

25 35.99N. 122 41.69E. CTD #47 deployed 0810z 08/18/09

25 36.00N. 122 41.63E. CTD #48 deployed 0904z 08/18/09

25 36.01N. 122 41.64E. CTD #49 deployed 1004z 08/18/09

25 36.14N. 122 41.80E. CTD #50 deployed 1113z 08/18/09

25 36.00N. 122 41.68E. CTD #51 deployed1224z 08/18/09

25 36.00N. 122 41.68E. CTD #52 deployed 1306z 08/18/09

25 36.04N. 122 41.68E. CTD #53 deployed 1418z 08/18/09

25 36.03N. 122 41.75E. CTD #54 deployed 1508z 08/18/09

25 36.05N. 122 41.72E. CTD #55 deployed 1605z 08/18/09

25 36.00N. 122 41.68E. CTD #56 deployed 1720z 08/18/09

25 35.93N. 122 41.69E. CTD #57 deployed 1807z 08/18/09

25 36.01N. 122 41.66E. CTD #58 deployed 1905z 08/18/09

25 36.07N. 122 41.72E. CTD #59 deployed 2005z 08/18/09

25 35.96N. 122 41.80E. CTD #60 deployed 2105z 08/18/09

25 36.03N. 122 41.68E. CTD #61 deployed 2205z 08/18/09

25 36.03N. 122 41.68E. CTD #62 deployed 2312z 08/18/09

25 36.03N. 122 41.68E. CTD #63 deployed 0005z 08/19/09

25 36.04N. 122 41.68E. CTD #64 deployed 0103z 08/19/09

25 36.08N. 122 41.71E. CTD #65 deployed 0205z 08/19/09
25 36.04N. 122 41.71E. CTD #66 deployed 0304z 08/19/09
25 36.00N. 122 41.60E. CTD #67 deployed 0406z 08/19/09

And the following ~3hourly bongo net casts were taken:
25 36.00N. 122 41.64E. Bongo #7 deployed 2300z 08/17/09
25 35.81N. 122 41.92E. Bongo #8 deployed 0038z 08/18/09
25 36.00N. 122 41.64E. Bongo #9 deployed 0508z 08/18/09
25 35.96N. 122 41.62E. Bongo #10 deployed 0740z 08/18/09
25 36.00N. 122 41.65E. Bongo #11 deployed 1046z 08/18/09
25 36.09N. 122 41.96E. Bongo #12 deployed 1345z 08/18/09
25 36.22N. 122 42.21E. Bongo #13 deployed 1646z 08/18/09
25 35.92N. 122 41.93E. Bongo #14 deployed 1935z 08/18/09
25 36.03N. 122 41.68E. Bongo #15 deployed 2245z 08/18/09
25 36.02N. 122 41.72E. Bongo #16 deployed 0132z 08/19/09

5) A drifting sediment trap was deployed and recovered at the following locations and times (red track in Figure 2):
25 33.33N. 122 39.29E. Sediment trap deployed 0545z 08/19/09
25 34.68N. 122 41.14E. Sediment trap recovered 0913z 08/19/09

6) Another transects involving CTD casts and the Hydrographic Sonars to map the edge of the Kuroshio (black transect and black open circles in Figure 2)
25 34.68N. 122 41.33E. CTD #68 deployed 0924z 08/19/09
25 42.96N. 122 46.87E. CTD #69 deployed 1055z 08/19/09
25 06.81N. 122 46.85E. CTD #70 deployed 1530z 08/19/09
25 09.37N. 122 43.51E. CTD #71 deployed 1628z 08/19/09

7) The above transect was aborted to rescue a RADOSA from Chinese fishing boat. The RADOSA was rescued and re-deployed as follow (black diamonds in figure 2):
26 01.72N. 122 41.95E. RADOSA on recovered 0120z 08/20/09
25 51.72N. 122 44.54E. RADOSA deployed 0318z 08/20/09

8) After rescuing the RADOSA, the transect of point 7 was resumed (yellow track in Figure 2. Note that this is a partial track as some of the data appears to have

been lost. Technicians on the R/V Revelle are trying to rescue the data.).

9) We returned to port of Keelung on August 21, 0800 local time.

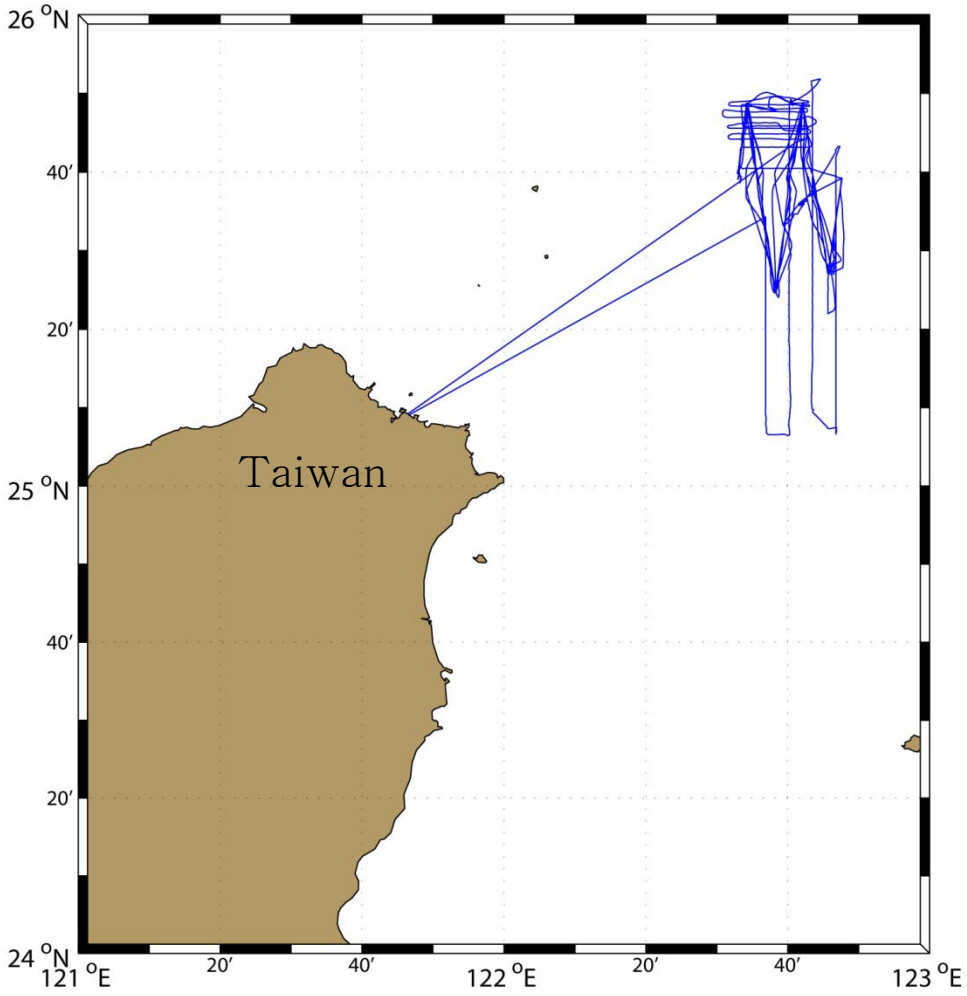

Figure 1: Ship track of R/V Revelle cruise in 08/13 – 08/21 2009 (blue line).

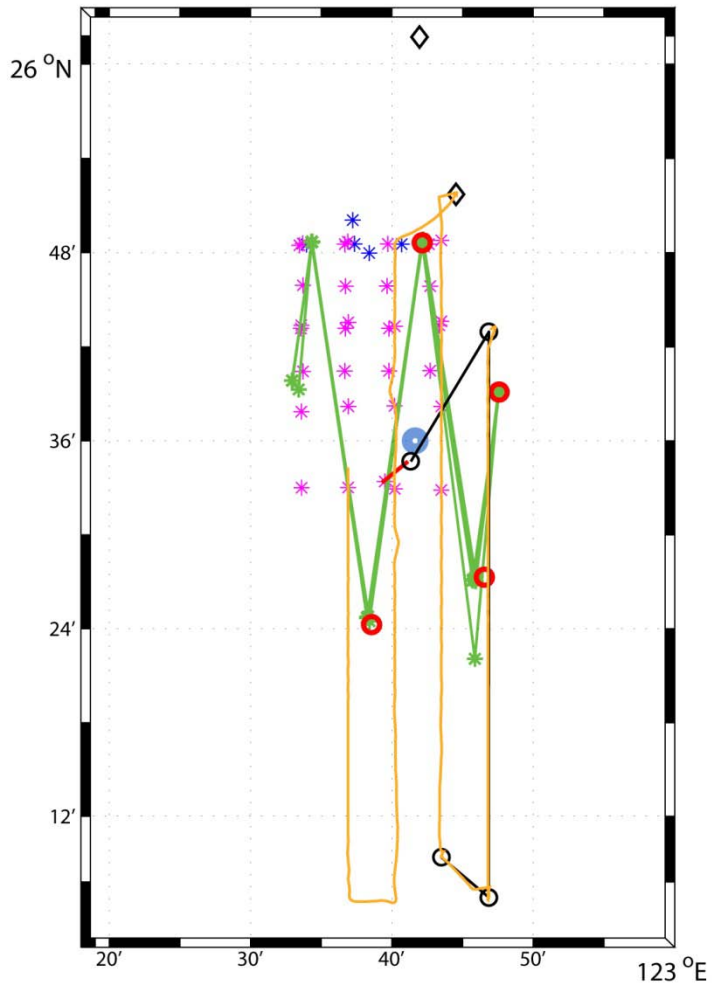

Figure 2: summary of cruise activities. See main text for marker's description.

SCHEDULE OF DATA DELIVERY:	
Data Description	Date of Expected Delivery to Dept. of State
shipboard CTD, shipboard ADCP, multibeam, underway data, drifters and RADOSA data	We expect to deliver the data at the end of the QPE project, around September 2011.